Transferring, Translating and Transforming: An Integrative Framework for Managing Knowledge across Boundaries

Paul R. Carlile
Sloan School of Management
Massachusetts Institute of Technology
E52-567
Cambridge, MA 02142
617-253-7782 (T)
617-253-2660 (F)
carlile@mit.edu

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Abstract

Organizations must establish processes for managing knowledge across boundaries because of the specialized and task-dependent forms of knowledge required to deliver products and services. To address this challenge an integrative framework is developed that identifies and integrates the value of different approaches to managing knowledge in organizations that are often presented as incompatible in the literature. The framework describes three progressively complex types of boundaries: syntactic, semantic and pragmatic. Each increasingly complex boundary requires a more complex process to facilitate communication and innovation across specialized forms of knowledge. The framework categorizes types of boundaries, gauges their complexity, and then describes the processes involved in managing knowledge across each of them. The development of a new engineering tool in an automotive firm is presented to illustrate the conceptual strength of this framework.

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1.0 Introduction

The importance of sharing knowledge in product development efforts cannot be stressed enough (Hargadon and Sutton, 1997). Nonaka (1994) and others (Leonard-Barton, 1995) have outlined the importance of knowledge creation and transfer in driving innovation in product development. The burgeoning industry of knowledge management claims that communicating knowledge is fundamental to organizational success (Davenport and Prusak, 1998). From a strategic perspective, the knowledge held by the firm is framed as the bedrock source of competitive advantage with strategic importance to organizations (Teece, 1998; Argote and Ingram, 2000). However, managing this critical resource is more difficult than expected. Many have begun questioning “knowledge management” initiatives (Newcombe, 1999; Southon, 1999; Tiwana, 1999) to the point of seeing them as potentially yet another academic or managerial fad (Abrahamson, 1996; Swan, Scarbrough and Preston, 1999).

This paper suggests that the puzzle of knowledge management has arisen because the nature and dynamics of knowledge have outstripped both our theoretical and managerial frameworks, creating a disparity between what we expect from knowledge management initiatives and what they ultimately deliver. A primary reason for this divide is that there are several approaches to knowledge in organizations and they offer varying and sometimes incompatible views. There are mechanistic perspectives that focus on knowledge as something to capture, store and then transfer. More cultural approaches emphasize the requirements of social interaction in translating knowledge before it can be shared. Others call attention to the “contested” or “political” nature of knowledge and the inherent, often prohibitive barriers this places on sharing knowledge. Without a way to integrate the value of these different approaches, our insights into the processes necessary to deliver more effective knowledge initiatives will remain under-specified, while frustration with the use of knowledge as a strategic resource will continue to grow.

The purpose of this paper is to provide an integrated framework to understand these different approaches and their collective value by focusing on the challenge of sharing knowledge across boundaries. The development of this integrative framework builds upon my previous empirical work examining knowledge and boundaries in product development settings (Carlile, 2002; 1997). The framework describes three progressively complex types of boundaries—syntactic, semantic and pragmatic—each managed by a different process—transfer, translation and transformation. The value of this framework is that it categorizes the relative complexity of different types of boundaries, and delineates definable processes of managing knowledge across them.

Complex knowledge boundaries are especially acute in the early stages of product development. The following description offers a glimpse into the challenges at this initial stage, and provides an introduction to the case that I will use later in the paper to illustrate the conceptual and practical value of the framework.

> Beta Motors, like any complex product development firm, faces significant challenges in the early design stage of a new product. This "fuzzy front-end," as it is called, represents a unique opportunity to specify up-front the overall design space of the vehicle that will either increase or decrease hang-ups downstream: conflicts between engineering groups, launch delays, costly re-work on the line, even future warrantee issues. The functional groups at this early design stage come from vehicle styling, engine and power train, climate control and safety. These groups represent a collection of specialists who face different technical problems, use different expertise and methods, and are responsible for different outputs. Needless to say, conflicts abound and overall the results of this design stage for Beta have been disappointing.
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> Since the 1960s, the dominant object or method used by Beta to represent knowledge in this collective conversation among specializations has been the

> "clay model." However, increasing quality and time-to-market pressures in the 80's, have rendered the clay model inadequate in representing the differences and dependencies between groups that have to be worked out at such an early stage. By the mid-90's, Beta Motors was spending significant resources to find a better way to work through this fuzzy front-end and capture the strategic opportunity it could be at this early stage. One such effort was the development of an engineering tool used to re-design one of Beta's most successful vehicles.

The next section provides an overall description of the framework focusing on the properties of boundaries. I then position each type of boundary in the framework and describe its respective knowledge processes in relation to the existing literature on knowledge in organizations. Next, the case is described to illustrate the value of the framework by explaining both a "successful" and a "failed" effort to manage knowledge across boundaries. The last section discusses what is required to establish effective boundary processes and how to apply this framework to the challenges of managing knowledge across boundaries.

2.0 Framing the Complexity of Knowledge Boundaries

In product development settings, knowledge boundaries are inescapable because of the hierarchical and functional specialization of knowledge. Additionally, since all of the inputs cannot be known in advance, these boundaries are dynamic and the "collective" knowledge to produce products is based on ongoing inputs that change throughout the process. For example, if the engine group develops a new diesel engine that is larger and has greater cooling requirements than previous models, the new engine's impact on the car's climate control system will only be completely determined after various components has been built and tested. The dynamic nature of the different requirements between and dependencies among engineering groups brings into focus the complexity of sharing knowledge and collaborating across boundaries.

To talk meaningfully about the complexity of boundaries and the challenge of managing knowledge across them, I have found it useful to identify two properties of a boundary. The first property of a boundary is difference. From a knowledge perspective, differences at a boundary arise from variation in the type of skills and backgrounds or amount of experience between individuals or groups. If there is no difference between individuals or groups then the boundary is not a consequential one. At a conceptual level, by difference I do not mean simply the difference between A and B (i.e., A – B), but rather that the differences between A and B arise from the fact that they occupy different "thought worlds" (Dougherty, 1992). Using a more geometric expression we could say that the difference between A and B arise because they occupy different positions relative to each other—they specialize in different problem-solving domains. For example, engineers in styling, engine and power train, climate control and safety specialize in different kinds of engineering work and problems, where different types of task, methods and outcomes are required. When knowledge is localized around different problems, this specialization, even if it is very small, creates difference that generates a potential boundary. Going back to the geometric expression, the farther apart the relative positions of A and B, the greater the difference.

At Beta Motors difference arises from variation in formal education, training, and types of methods used by styling, engine and power train, climate control and safety engineers. The most common way to conceptualize these sources of difference is to frame them in terms of specialization (Weber, 1947). However, it should be recognized that this specialization goes deeper than just an individual's role; it extends to the different problems or tasks that each is responsible for and requires specialization in. The styling group creates a distinctive vehicle, compared to its competitors. The engine and power train group develops the most efficient engine possible. Climate control adequately cools the vehicle in summer and heats it in winter.

Safety ensures that the vehicle is as safe as possible for its occupants, as well as for the occupants of another vehicle with which it may collide.

The second property of a boundary is dependence. Dependence is a relation that exists between individuals or groups. If there is no dependence between individuals or groups that are different then there is no consequential boundary. In our geometric example, if A and B are dependent on each other, they constrain or have consequences for the other's movement. For example, the dependencies between engine/power-train and vehicle styling comes with the recognition that a bigger engine will raise the level of the hood; while the desired "look and feel" embodied in the various renderings will constrain the size of the engine. Clearly, dependence across these different positions (i.e., specialized domains) are not always simple, neutral relations, but generate consequences and sometimes conflicts. Overall, the more difference and dependence there is at a given boundary the more challenging and complex it is to cross.

In organizational theory literature there are two dominant expressions of the idea of dependence, one direct and the other more indirect. The direct expression comes from Emerson's (1962) use of the word dependence to explain power relations, which was then built upon by Pfeffer and Salancik (1974) in the resource dependency model. Here the differences in resources accumulated by various groups and the dependencies among those groups determine the current status of power relations. The indirect conceptualization stems from Thompson's (1967) discussion of interdependence (i.e., serial, pooled and reciprocal) as a way to describe increasingly complex ways of organizing for a task. As used here, interdependence implies that the relations across elements in the system are well defined, that is, that the differences and dependencies in the system are known. The similarity between Emerson and Thompson is that they describe situations where the differences and dependencies that exist, are either known in advance or are stable. Their conceptualization of dependence is limited when applied to situations where conditions are less stable.

The varying conditions from stable to more fluid impact how we describe the complexity of the relations at a boundary. When differences and dependencies are known and the conditions surrounding them are stable, managing the boundary is straightforward. However, when new differences and dependencies arise, managing the boundary becomes progressively more challenging. For example, if a previous engine is re-used in a vehicle redesign, there is a significant amount of shared knowledge that makes managing the boundaries across styling, climate control and safety much easier. Using a new engine generates considerable novelty about what differences and dependencies are relevant, and how they will be recognized and dealt with between groups. Like most product development firms, at the fuzzy front-end each group in Beta Motors needs to put in their newest technology or their newest approach into the product to remain competitive. This newness generates novelty in the amount of difference between groups, but also increases the novelty of what dependencies are consequential at the boundary.

We can scale these varying conditions of a boundary along a vector, starting with known and moving outwards to increasing novelty. Figure 1 represents these variable conditions along with the properties of difference and dependence. The shape of this inverted triangle represents a way to gauge the complexity of a given boundary between two specialized entities—called here Group A and Group B. Although I made an analytic separation between difference and dependence above, I indicate that at any boundary both properties have to exist. Starting at the origin differences and dependencies are known, thus the complexity of the boundary between Group A and Group B is minimal. However, as novelty increases the amount of difference or "gap" at the boundary grows, so closing the gap takes progressively more time and resources.

Figure 1 then offers a way to gauge the complexity of sharing knowledge across a boundary. For example, when Group A and Group B are specialized in different knowledge domains and have many dependencies in completing a task, the boundary is complex. However, even under these complex circumstances, if Group A and Group B have previously accumulated shared knowledge in working together at the boundary and the boundary remains stable, then managing the differences and dependencies will be much less challenging than when novelty is present.

Figure 1
Gauging the Gap: Framing the Complexity of a Boundary

The path-dependent nature of knowledge has a positive effect when the conditions of its reuse are stable, similar to what was faced before (March, 1972). However, when novelty increases, the path dependent nature of knowledge has negative effects (Hardagon and Sutton, 1997), because what is known or used before may not take into consideration the novelties present in the next cycle (Carlile and Rebentisch, 2001). Given the tremendous time pressures under which individuals must take action, their familiarity with what they have done in the past can make individuals mis-recognize what is novel as something that is already known (i.e., competency traps; Barnett and Hansen, 1996). Without the recognition of novelty (new differences and dependencies that have arisen), the gap at the boundary cannot be effectively managed. This is why the knowledge a group currently uses is such a problematic anchor point when novelty arises (Carlile, 2002).

3.0 Developing the Integrative Framework

In this section, I link the discussion of boundary complexity (Figure 1) to the syntactical, semantic and pragmatic approaches to boundaries developed in my earlier work (Carlile, 2002; 1997). This effort leads to the development of a framework that represents this increasing complexity and integrates the various literatures on knowledge in organizations

3.1 Syntactic Boundary: Transferring Knowledge

The most common label used to describe the movement of knowledge in organizations is "knowledge transfer" (Winter, 1987; Kogut and Zander, 1992; Nonaka, 1994; Szulanski, 1996; Argote, 1999). The concept of "transfer" has its roots in mathematical information theory (Shannon and Weaver, 1949) and can be found in the information processing approaches to boundaries and organizations (Ashby, 1956; Lawrence and Lorsch, 1967; Galbraith, 1973; Allen, 1977). The practical strength of Shannon and Weaver's framework is founded on a syntactical view of information, where a boundary can be dealt with in a straightforward manner because a common syntax (i.e., 0's and 1's) or language between the "sender" and "receiver" is shared. When a shared syntax or language sufficiently specifies the differences and dependencies at the boundary the boundary is "unproblematic;" the primary concern becomes "processing" or transferring knowledge through this shared syntax.

This syntactical view has, not surprisingly, become the most dominant approach in the "knowledge management" industry over the past decade driven most strongly by information technologies and technologists. Knowledge management has largely been focused on the capture, storage and retrieval of knowledge. This is why creating "taxonomies" and "repositories" are seen as the primary solution in technical knowledge management systems (Davenport and Prusak, 1998). The positive impact of these knowledge management systems has been limited to situations where a shared and stable syntax exists so that taxonomies can be easily built upon them. However, when novelty increases a syntactical approach to knowledge management proves disruptive since the taxonomy is not effective at managing the differences and dependencies at the boundary.

Beyond this storage and retrieval model that dominates the knowledge management industry, much contemporary research on knowledge transfer focuses on one-way movements of knowledge, learning, or "best practice" from one place to another (Argote, 1999; Szulanski, 1996). This rich stream indicates that transfer success is enhanced significantly when the differences (i.e., geography, type of customers, access to resources) across the parties are small. This finding underscores that successful movements of knowledge occur when the parties are specialized in the same type of activity, so the primary difference is only that the sender is experienced in the best practice and the receiver is not.

In the early design phase at Beta Motors, when there is a shared language and a clear understanding of the joint specifications between the engine/power-train group and the climate control group, their specialized forms of knowledge can be efficiently represented and critical task dependencies identified. The *value of a syntactical approach* to managing knowledge across a boundary is realized when a shared and stable syntax/language exists. Based on this knowledge can be efficiently transferred at the boundary. Such a shared and stable syntax/language is constructed from previous efforts at a boundary to address the critical differences and dependencies between the two groups—and once established only the *costs of transferring* knowledge are faced at the boundary.

The *challenge to a syntactical approach* to managing knowledge across a boundary occurs when novelty increases. Under these conditions a shared and sufficient syntax that had been used in the past is no longer able to address the novel differences and dependencies which arise. So, while a shared syntax is necessary, it is not always sufficient to address all conditions at a boundary. This potential insufficiency often goes unrecognized from both an academic "information processing" perspective and a narrow technological (i.e., taxonomies and repositories) approach to knowledge management initiatives. The limitation we face with this transfer logic is the uncritical assumption of the adequacy of the syntax or language used (Reddy, 1979). In the case of the fuzzy front-end, the clay model is limited: the syntax that it embodied was no longer sufficient to represent the critical differences and dependencies that now had to be resolved among the four groups. Novelty had arisen because the “customer” made new requirements, each specialization created new technologies, and the consequences of differences and dependencies across the four groups had to be resolved much earlier because of the new quality and time-to-market demands now present.

As novelty increases and the sufficiency of the current syntax reaches its limits, a more complex knowledge boundary is faced and a more complex boundary process is needed. Empirical studies (Epple, et al., 1991; Szulanski, 2000; Argote and Darr, 2001) show that successful knowledge transfer requires mutual learning and an adaptive process. It is this process of learning that is required in the next, more complex, type of knowledge boundary.

3.2 Semantic Boundary: Translating Knowledge

A semantic approach to crossing a boundary recognizes that problems of interpretation exist because the contexts in which people develop their knowledge are different or as novelty increases, interpretive or semantic differences as to what a word, measurement or outcome means arise at a boundary. Under these conditions a shared or an agreed upon syntax to resolve those differences is lacking. This is why studies from an interpretive approach emphasize processes that create “shared meanings” (Dougherty, 1991) or mechanisms “to reconcile discrepancies in meaning” (Nonaka and Takecuchi, 1995: 67).

The “community of practice” literature (Lave and Wenger, 1991; Brown and Duguid, 1991; Wenger, 1998) recognizes the challenges created by these semantic or interpretive issues and has strongly influenced our approaches to learning and knowledge in organizations. In the foundational work, Lave and Wenger's empirical focus was a "within" practice view—in their case, the practice of tailoring in West Africa. Within this shared practice the primary phenomenon highlighted was how young apprentices became tailors through a process of "situated learning" that Lave and Wenger described as "legitimate peripheral participation" (1991: 29). This learning between "newcomers" and "old-timers" can best be described as interpreting or translating the meaning or knowledge used as both participate in the practice of tailoring. Frequently highlighted in the community of practice literature is the role of "stories" as an effective means of sharing knowledge and meaning (Wenger, 1998). In Orr's (1996) study of Xerox repairman, "war stories" proved an effective tool in sharing knowledge about the complex technical and social situations that arise when repairing a copier. The basis of effectively interpreting and learning from these stories existed because the practice of Xerox repair was shared (i.e., similar problems, similar techniques, and similar interests) by Xerox repairmen. However, when working across a boundary between different types of specialized domains or practices, where tasks, methods and interests are often quite different, too little is shared for stories to be effective at resolving differences and creating shared agreements. This explains the limitations of the communities of practice approach when applied to task where working "across" practices or specialized domains is required in creating complex products.

Nonaka focuses on these "across" functional issues when he lays out his organizational knowledge creation and transfer cycle (1994; Nonaka and Takeuchi, 1995). Nonaka's major focus on the challenge of sharing knowledge in organizations is making tacit knowledge (Polanyi, 1966) explicit. In Nonaka's approach, tacit knowledge is hardest to share and is surfaced in communities of interaction where the "interpretive" differences across functions are translated through a process he calls “externalization.” Nonaka emphasizes this process of externalizing as the critical task in making tacit knowledge explicit, driving the overall knowledge creation and transfer cycle (Nonaka, 1994). However, as novelty continues to increase there is often a lack of shared background and interests to work across a boundary. Additionally, the knowledge developed by one group may have negative consequences for another group. In this case, simply making one’s knowledge explicit to an individual in another practice may actually make matters worse. When moving knowledge across boundary often the problem is one of different interests, not just different meanings that need to be reconciled. Under these conditions the negative consequences produced at a boundary have to be resolved through changing the knowledge currently used at the boundary.

The *value of a semantic approach* is it recognizes that to manage knowledge across a boundary that interpretive differences must be reconciled and a shared meaning created. A shared practice provides a basis where through learning and translating knowledge “new agreements” are created which provides a more sufficient shared syntax to reconcile differences at the boundary. The costs associated with a semantic boundary are the *costs of translating* knowledge at the boundary in order to create shared meanings. However, when working “across” different kinds of specialized practices a more challenging boundary is faced.

The *challenge to a semantic approach* to managing knowledge across a boundary is when creating new agreements is not enough to resolve the negative consequences at the boundary. Resolving negative consequences is not just a matter of creating or adding new knowledge, but changing the current knowledge used to accommodate the creation of new knowledge that resolves these negative consequences. At the fuzzy front-end it is not just a matter of the engine and power-train group learning about crash test results from safety, but altering the current design of the engine to accommodate a better crash test result (i.e., better bumper location, "acceptable" intrusion into passenger compartment). This process of changing the current knowledge used to resolve the negative consequences present (i.e., "creative abrasion," Leonard-Barton, 1995) is left un-specified in Nonaka's knowledge creation and transfer spiral. Nonaka recognizes the challenges that arise because knowledge exists in different forms (i.e., tacit and explicit), but he does not recognize the negative consequences generated because knowledge is localized, embedded and invested in different kinds of practices (Carlile, 2002).

Under these circumstances, individuals at the boundary face significant costs in representing and then changing the knowledge they currently use to accommodate the novelty present at the boundary. In the case of the clay model, it lacked the capacity to represent the differences and dependencies now faced by the four groups. Without this representational capacity the groups involved could not use it to identify the negative consequences that would have to be resolved to change the design of the vehicle. In situations where differences are more than semantic, knowledge sharing across a boundary becomes problematic.

3.3 Pragmatic Boundary: Transforming Knowledge

A pragmatic approach to knowledge and boundaries (Carlile, 2002) recognizes that groups with different knowledge bases that are dependent on each other often generate negative consequences. This approach is resonant with William James' method of pragmatism: "there can be no difference anywhere that doesn't make a difference elsewhere" (James, 1907: 45)—i.e., no difference that is dependent on something else can be inconsequential. Given the novelty that naturally arises in product development settings, negative consequences between groups are a natural outgrowth of developing new knowledge and products. This is why knowledge itself must be recognized as problematic; that is, it can be barrier as well as a source of innovation.

To understand the problematic nature of knowledge, it must be understood as localized, embedded and invested in the tasks, methods and outcomes of a specific practice (i.e., knowledge-in-practice; Carlile, 2002). Knowledge is costly to develop (i.e., education, training, experience) and to change, so it should be seen as "at stake" for the individuals in a given practice (Bourdieu and Wacquant, 1992). This helps us see more clearly why accommodating the knowledge of another group is not a neutral or costless effort. The cost for any group dealing with increasing novelty at a boundary is not just the *cost of learning* about what is new. It is also the *costs of adjusting* or *transforming* their "current" ways of doing things to accommodate the knowledge developed by another group to collaborate at a boundary. By characterizing knowledge-in-practice, we can see better why and how individuals are inclined to take action along a path dependent trajectory, given that they have accumulated their knowledge using the tools and methods to solve problems in their specialized domain or practice (Bourdieu, 1980).

In the early 1990s, the engine and power train group wanted to place their newest, most powerful engine type into the vehicle. This engine type was a breakthrough for the engine group because it produced significant horsepower while still achieving "good" gas mileage. Even though these results came from a working prototype, it represented an outcome of a long and sustained effort over several years. The problem, however, was that the shape of the engine caused the hood to go up much higher than the styling group wanted. Unlike the 1980s when "bulky" trucks were the norm, in the 1990s competitors were creating and the market was demanding increasingly aerodynamic trucks. Something would have to change to resolve this conflict between the engine/power-train and styling groups. Unfortunately both groups had invested a great deal of time and energy creating knowledge to solve their respective problems. For the engine/powertrain group the novelty encountered at this boundary was a smaller engine compartment. For vehicle styling it was a fuel-efficient engine that was too big. The practical challenge in dealing with and resolving the consequences at a pragmatic boundary is for each side to represent, specify, negotiate, compromise and transform their current knowledge to accommodate the novelty present at the boundary.

The *value of a pragmatic approach* is it recognizes that to manage knowledge across a boundary that new knowledge has to be created, and to do that current knowledge used at the boundary has to be negotiated and transformed. This pragmatic approach is not simply a process of just adding or combining knowledge, nor is it one of jettisoning the old knowledge and bringing in all new. Here a complex boundary process has to be developed where current and more novel forms of knowledge can be represented, learned about, and then jointly transformed. Through such a process, a composition of known and more novel differences and dependencies are collectively transformed resolving the negative consequences at the boundary. As compared to a syntactic boundary or a semantic boundary and their associated costs (i.e., costs of transferring and translating knowledge), crossing a pragmatic boundary entails the additional *costs of transforming* knowledge to manage knowledge across that boundary. In a pragmatic approach, each group identified the differences and dependencies that are relevant to their group, negotiates alternatives at the boundary and then collectively transforms the knowledge currently being used in relation to the novelty recognized.

The *challenge to a pragmatic approach* to managing knowledge across a boundary is that representing differences and dependencies, learning about their consequences and then transforming knowledge is a complex process to develop and maintain. A complicating factor in maintaining a complex boundary process is that as such a process is re-used in a new product cycle the process too may have to be changed as well (Carlile and Rebentisch, 2001). For example the clay model's representational capacity to support such a pragmatic process was undermined as the conditions at the boundary became increasingly novel during the 80's and early 90's. The clay model could no longer represent the differences and dependencies that were relevant across the four groups involved as it did not provide a means for them to collectively make trade-offs and transform their current knowledge.

3.4 The Integrative—"3-T"—Framework

The purpose of this review and framework development has been to clarify the different approaches to knowledge and boundaries that can be identified in the literature (see Table 1 for summary). In Figure 2 each type of knowledge boundary is used to categorize the complexity of the boundary framework described earlier. This framework recognizes the importance of three boundary processes—transferring, translating and transforming—the 3-T framework. The tip of the inverted triangle represents those unique situations where the syntax is shared and sufficient, so knowledge can be efficiently transferred across the boundary. As novelty begins to increase a syntactical approach can still be effective if the consequential or requisite differences and dependencies are clarified at the boundary (i.e., the concept of requisite variety; Shannon and Weaver, 1949; Ashby, 1956; Weick, 1979). As novelty increases and the gap grows, new differences and dependencies arise that have to be identified and their consequences understood. This is a semantic boundary and in some cases new agreements can be created to resolve these consequences. However, as novelty continues to increase and the gap gets larger, a pragmatic boundary is faced. To address this larger gap, current knowledge needs to be changed to accommodate the creation of new knowledge that addresses the novelty present and the negative consequences that have been identified.

Figure 2
A 3-T Framework for Managing Knowledge Across Boundaries

Figure 2 should not be read as a formal hierarchy in the sense that to get to a pragmatic boundary you have to go through the first two. Its purpose is to categorize and gauge the size of the gap—the complexity of a boundary faced—to clarify the types of processes necessary to manage knowledge across it. At a pragmatic boundary Figure 2 suggests that all three boundary processes need to be used to manage knowledge across the boundary. At a semantic boundary translation and transfer processes are required; and at a syntactic boundary a transfer process is required. The question that remains, however, is what are the requirements involved in such boundary processes?

Research on boundary objects (Star, 1989) has begun to address the question of what allows an object or tool to be effective at one boundary and not another (Carlile, 1997). I have identified three following characteristics (Carlile, 2002) that we might expect to see in an effective boundary process as well: establishes a shared language to represent knowledge; provides a concrete means of specifying differences and dependencies; and facilitates a method in which individuals can jointly transform the knowledge used. This research is different from my previous work in that it focuses not just on the physical artifacts or boundary objects per se, but seeks to identify more generally the underlying characteristics of a "boundary process" or "boundary infrastructure" (Bowker and Star, 1999). To identity these characteristics of a boundary process I will focus on the fuzzy front end at Beta Motors as an example of a pragmatic boundary and discuss the development of an engineering "tool" and its use in addressing downstream design problems not identified and resolved using the clay model.

4.0 Empirical Approach and Case

I began collecting the case data during a follow-up visit to Beta Motors where I had previously completed a study (Carlile, 1997). These data were collected over a period of two months and included seven interviews with the principal actors and four follow-up telephone interviews to clarify particular points. Although the case data were collected somewhat opportunistically, they are part of a larger set of empirical work along similar themes (Carlile, 2002; Carlile and Lucas, 2001). The focus of the case was on the development of a computational fluid dynamics (CFD) technique. This "tool" was used in four different vehicle re-design settings; three were successful and the fourth wasn't. First, I describe how the tool was developed and then "successfully" used on the B-150 platform. Next, I will discuss the characteristics that define an effective boundary process at a pragmatic boundary and link these characteristics to the integrated framework. Finally, I discuss the "failed" use of the tool on the B-100 platform and summarize what can be learned from this about managing knowledge across boundaries.

4.1 Case: Developing and Using the CFD Tool

With the launch delays and quality concerns that Beta Motors had been facing, in the 1990s the head of the engineering group was looking for a better way to manage the "fuzzy front-end." Bill Knox was asked to develop a tool to make "communication and problem solving" more effective across the four major groups—vehicle styling, engine and power-train, climate control, and safety—involved at this early design stage. What makes this task particularly hard is that the problem of defining form, fit and function are dispersed across several specializations. For example, styling wants to create an aesthetically "distinctive" vehicle design that differentiates it from competitor products (i.e., slope of the engine hood and the overall "look and feel" of the car). The engine group has horsepower requirements and fuel economy constraints that are influenced by weight and airflow across the vehicle. The climate control group has to make sure that, given the engine size, the vehicle can stay cool in the summer and warm in the winter with a grill size that doesn't compromise aesthetics. The safety group has concerns about the placement of bumpers and the location of the engine to limit collision damage to their car and other vehicles involved. In each case, the requirements of one group create dependencies that constrain the ability of another group to meet their requirements. For Bill, “knowing your limitations [in a design] is about understanding the interdependencies across all the groups involved.”

The increasing competitive pressures in the 1980’s meant that design problems had to be identified and resolved much earlier to meet new quality and product cycle expectations. The clay model could not represent the various differences and dependencies now required at this early stage. However, since clay models were developed very early in the process by vehicle styling, and given their historical use, they remained a powerful tool used to shape the design of the car. This was not only due to the engineering culture at Beta Motors, but reflects that clay models represented the “look and feel” important in distinguishing a design against the “look and feel” of the competition. For Bill Knox, what was missing was a tool so that the groups involved could use to represent “all that goes into defining the gross shape of the vehicle. That way they can know critical dependencies, and when there is a discrepancy you can test it and find out what it is.” Having a Ph.D. and being a specialist in aerodynamics, Bill had developed several Computational Fluid Dynamic (CFD) models to make assessments of the aerodynamics and fuel economy of several vehicles. This time he hoped to model not just the aerodynamics of the car but the dependencies between the different design parameters of each group involved that determined its gross shape and that would “improve discussions and more give and take would occur.” At a more technical level, he hoped by providing an overall measure of the vehicle’s drag (i.e., drag coefficient) and representing the “skin” of the vehicle through a CAD module that the

CFD tool would “increase the amount of trial and error problem solving possible at such an early stage.”

Bill often made references to a firemen’s tarp to create an image of the role that he saw CFD modeling playing. A firemen’s tarp was used in the early 20th century to catch individuals jumping from burning buildings. Bill always reminded me that the effectiveness of the tarp came from three things. First, it had to be made of a strong material and fashioned in a way that each fireman could easily hold and use it. Second, it needed to be held by several firemen pulling as hard as they can in different directions for it to break the fall of the individual safely. And third, the firemen had to constantly look up and then make some adjustments to make sure the individual landed safely in the middle of the tarp. So, Bill set out to create a modeling tool that would establish a “shared way for each group to pull on and collectively make better trade-offs.”

Over a period of four months Bill consulted each group to understand its “form, fit and function” parameters. This information would provide the technical basis of specifying each group’s knowledge and interests (i.e., preferences, new technologies, test results, etc.) to each other. During this time he learned how to specify their mutual constrains or the critical dependencies between groups. This provided a means of learning and arbitrating the trade-offs as collectively modeled by the “skin” of the car and its drag coefficient. Bill was careful to use each groups own language as best he could to make the tool more accessible.

After six months of building and fine-tuning, the CFD modeling tool was given to the four groups involved in the re-design of the “B-150”, one of the company’s most successful vehicles. The effectiveness of the tool was significant, both in terms of engineering time and prototyping costs, but more importantly, the downstream implementation of the B-150’s re-design went very smoothly and avoided any major rework costs and launch delays. Before these downstream successes were evident, the tool was also used in three other early vehicle re-design stages. Two had similar successes to the B-150; the other, the B-100, had similar savings in engineering time and up-front cost, but ended up generating significant design problems and delays downstream.

4.2 The Characteristics of an Effective Boundary Process

To explain the different outcomes in the use of the CFD in the B-150 and the B-100 I will discuss four characteristics of any boundary process used to manage knowledge across a pragmatic boundary. The first three build upon the characteristics of effective boundary objects identified in my previous research (Carlile, 1997; 2002), and the fourth characteristic was identified in this research.

The first characteristic required to effectively manage knowledge across a pragmatic boundary is the development of some shared language or syntax to represent knowledge at the boundary (see Figure 3, #1). When Bill developed the modeling tool he was able to establish a minimum amount of shared language or syntax across vehicle styling, engine/power-train, climate control and safety. This consisted not only a shared language about using the tool, but also a shared language of how the dependencies across design parameters (i.e., shape, geometry, requirements, weight, etc.) will be measured. For example, the size of the grill has long since been a contested space between vehicle styling and the more engineering oriented groups because the grill strongly impacts the look of the vehicle, but is also strongly determined by engine and climate control requirements. With a common language to compare design parameters, the re-design of the B-150 was the first time the actual grill on the production vehicle was almost the same size as the one defined at this early stage.

The existence of a "shared" language is a primary focus of a transfer approach, where a common language or syntax has to be developed. It served as a basis for identifying what was consequential and that additional problem-solving was still required. A climate control engineer summed this up nicely, when he said, “we disagree sooner and know what we are disagreeing about more productively when we have a shared basis to compare our requirements.” In Figure 3, the characteristic of a “shared syntax” or “language” (#1) is placed at the bottom of the triangle to indicate its foundational role in supporting the other three characteristics. However, when novelty arises, syntax is not a sufficient condition.

The second characteristic required to manage knowledge across a pragmatic boundary is that the individuals involved need the ability to represent their preferences to others (see Figure 3, #2). For example, the power-train group preferred a newly-developed, larger engine, while the climate control group wanted a grill large enough for adequate air-flow. The safety group wanted to see a bumper design no higher than 16.5 inches from the ground to minimize collision damage and the vehicle styling group wanted a “sleek” design. Representing their current knowledge within their own practice (i.e., cutting edge technology, technical requirements and preferences) results in specifying the differences between groups. Identifying dependencies across these different specialized groups is also a necessary requirement in improving the design. Although the CFD model did not create a physical object, it did identify the dependencies of each groups inputs and a collective output with a level specificity and speed that was not possible with the clay model. For example, representing the larger engine showed how it affected the slope of the hood, increased weigh, size of the grill, and changed the location of the bumper in a manner that was impossible previously. From a technical point of view, CFD was use because it could specify the impact that the various design requirements had on each other.

This “process of learning” about the local differences between groups and their dependencies at the boundary is similar to a semantic approach to a boundary. The ability to represent and specify differences and dependencies allows the different groups to identify what is most consequential, then collectively prioritize their time and resources to resolve those consequences. Some consequences are resolved by creating shared agreements about what a specification or test result means. This is a recognition that differences are sometimes semantic and groups don't have to change their knowledge in order to work together. However, often dependencies generate negative consequences that can only be resolved if groups on one or both sides of the boundary change the knowledge they use.

The third characteristic required to manage knowledge across a pragmatic boundary is that the process or tool can be used to alter or transform the knowledge being used at the boundary (see Figure 3, #3). In cases where negative consequences exist, the groups involved must be able to change the knowledge that they are currently using to "try on" alternatives and make trade-offs to create new knowledge that accommodates the novelty identified. Being able to specify, negotiate, transform and validate knowledge lies at the heart of doing trial and error problem solving at a pragmatic boundary.

The cost of transforming knowledge is both the cost of learning new things or adjusting current knowledge to accommodate the creation of new knowledge. It is a pragmatic process, which requires transforming a mix of knowledge currently used with more novel forms of knowledge being identified at the boundary. By using CFD modeling, each group could represent the various concerns, data points, and requirements of each specialization and then engage each other to propose, negotiate, transform and verify the "new" knowledge that would be used to re-design the vehicle. The outcome of transforming knowledge is only justifiable if it can be validated according to some criteria agreed upon by the groups involved. The validation criterion may be a measure of cost, quality, time, or, in this case "drag-coefficient," as represented in the

CFD tool. Such a criterion or means of representing and comparing differences is established through the development of shared syntax and agreements. Much like the example of the firemen's tarp, the ability and willingness of individuals to change their knowledge or position only emerges when a process of identifying how it negatively impacts others is established.

The fourth and last characteristic of managing knowledge across a pragmatic boundary requires multiple interactions (see Figure 3, #4). The gap at many boundaries cannot be resolved with one try, but requires an iterative process of closing the gap—experimenting and shaping alternatives and solutions overtime. The content of what is iterated is generated by the first three characteristics, but the iterative quality of a boundary process is what allows individuals to expand trial and error opportunities in transforming a complex design. As the groups participate in each iteration they become better at learning about and representing what differences and dependencies are relevant or consequential to them at the boundary. Since knowledge is localized, embedded and invested in a given practice, such an iterative capacity is what allow knowledge to be un-invested, un-embedded and re-localized in new knowledge. One way to think about this gap-closing is that through each iteration more knowledge is transferred, translated and transformed—and with that effort a more sufficient syntax to manage the relevant differences and dependencies at the boundary is developed.

4.3 Understanding the Failure of the CFD Tool

When costs on the B-100 started showing up, Bill began investigating and eventually asked for my help in documenting the different outcomes generated using the tool. The critical difference identified in the interviews was that very early on in the process the deployment engineer had been pushing the team to reach a drag coefficient of 0.33. A drag coefficient of 0.33 had been the outcome reached at the end of the B-150 re-design. The rationalization for the deployment engineer's target of 0.33 was that B-100 was a "similar vehicle just on a smaller platform." Based on these similarities he and other individuals involved B-100 platform redesign believed that "the target of 0.33 was a justifiable place to start." Given these similarities, a drag coefficient of 0.33 was technically a defensible constraint for the B-100 re-design. However, specifying this technical target at the beginning overly constrained the *process* of representing and learning about what differences and dependencies were relevant to the four groups involved. Since a collective solution was settled on so early, many differences and dependencies were either not identified or, if identified, were not sufficiently specified to adequately resolve the negative consequences that eventually proved costly downstream.

When we think about problem solving across different specializations, we must visualize a complex, collaborative gap-closing process (Lave, 1988)—where all parties participate iteratively in representing their knowledge, trade-offs and potential solutions. Even though the numeric outcomes where similar (i.e., 0.33 drag coefficient) across the B-150 and B-100, the process of getting there was not. This pragmatic boundary process, or lack of it, made these identical numeric outcomes generate very different results downstream. For the B-150, this outcome was iteratively shaped by a pragmatic process, where the various differences and dependencies specified by individuals and represented in the CFD model transformed the design of the vehicle in a very effective way. For the B-100, the pragmatic process of representing knowledge, learning about what was most relevant and consequential and collectively transforming the design was truncated prematurely. In the end, the negative downstream consequences that arose with the B-100 platform resulted from a mismatch of taking a transfer approach to a pragmatic boundary—an approach that curtailed the processes of transferring, translating and transforming required at such a complex boundary.

5.0 Discussion

The different outcomes from the B-150 and B-100 platforms illustrate that an effective cross boundary process is hard to establish and then maintain. Depending on the type of boundary faced different combinations of characteristics of a boundary process or boundary infrastructure are required (see Figure 3). For example, if a syntactical boundary is faced, only characteristics 1 and 4 are necessary because given a sufficient syntax, it simply becomes a matter of transferring knowledge at the boundary (i.e., just processing costs). At a semantic boundary characteristics 1, 2 and 4 are necessary. Here with some shared syntax and a process of learning about differences and dependencies, new agreements can be created to reconcile the discrepancies identified without having to change the current knowledge used (i.e., processing and learning costs). At a pragmatic boundary characteristics 1, 2, 3 and 4 are necessary. Here to create innovation, current and novel forms of knowledge have to be jointly transformed in order to create new knowledge (i.e., processing, learning and adjustment costs) and resolve the negative consequences present.

Both the B-150 and the B-100 faced pragmatic boundaries, but only in the B-150 was the boundary process managed to effectively use all four characteristics. For the B-100, the boundary process converged too quickly around a “solution” (i.e., 0.33) that was more or less transferred from the B-150 setting. Under these circumstances significantly less knowledge was identified as relevant at the boundary. Given that, fewer negative consequences were understood, and even less knowledge was transformed. The significance of this poorly managed pragmatic boundary is that the groups involved failed to recognize just how ineffective the design they produced was until only after significant downstream costs were incurred.

A mismatch between a pragmatic boundary and a transfer approach is not unusual in organizations for both political and practical reasons. Since individuals are localized, embedded and invested in what they know, politically the most expeditious action is to re-use their knowledge. This tendency is what generates the path dependent nature of knowledge and learning (March, 1972; Huber, 1991; Hardagon and Sutton, 1997). When conditions are stable at the boundary, this path dependency is not only efficient but effective as well. However, because of this path dependent tendency and the strong pressures toward quick action in organizations, individuals often re-use their current knowledge even when novel conditions arise. Under these circumstances a mismatch often occurs because novelty is hard to recognize and costly to represent. We see this practical challenge in the use of the clay model and its limited capacity to represent differences and dependencies at the fuzzy front end. It was only after developing CFD the four groups began to successfully represent novelty at this early stage which helped Beta Motors to manage with the "rigidity" (Leonard-Barton, 1992) that had been growing in their product development process.

However, this mismatch between type of boundary and approach goes deeper. If one group recognizes novelty on their side of the boundary but cannot represent its consequences to the other side, this practical breakdown often leads to a political breakdown at the boundary. Eventually the limitation of the clay model was its capacity to represent differences and dependencies that were faced downstream—critical issues that were now generating negative consequences in terms of launch delays and cost overruns. As with any complex process (i.e., product development, public policy development, etc.) downstream interests generally have a harder time being represented, so downstream knowledge is politically weaker relative to upstream knowledge. This is why the clay model continued to be the dominant method used at the early stage into the 1990s; it represented what was at stake for the upstream group of vehicle style and their marketing VP champion. So at any boundary we cannot assume the parties involved occupy equal positions in representing what they know at the boundary. This is why the success of any boundary process is based on its capacity to represent the differences and dependencies on either side of the boundary. If the boundary object, tool or process does not provide a group the ability to represent their knowledge, then it is as if their knowledge does not exist—and for all political and practical purposes their knowledge and its value is of no consequence at the boundary. For all groups involved, it is their ability to create and explore the "knowledge potential" at the gap, where these practical and political abilities go hand in hand in transforming knowledge and generating innovation at a boundary.

Recognizing the political and practical issues that arise is consistent with practice-based view of knowledge (Carlile, 2002). Theories of practice (Bourdieu, 1980; Giddens, 1984) emphasize the importance of understanding one group's knowledge in relation to another's. It is not just a matter of understanding the situated meaning of knowledge, but its localized, embedded and invested character in relation to knowledge localized, embedded and invested in another practice. The focus on boundaries and the properties of a boundary—differences and dependencies—is a way to describe the relation between the knowledge used in one practice and the knowledge used in another. At a pragmatic boundary, where negative consequences naturally arise, we must frame a boundary process in terms of its practical (both groups can represent their knowledge) and political (both group can transform the knowledge to be used at the boundary) capacity.

6.0 Implications

This paper has described three different types of boundaries and developed an integrative framework to resolve many of the incompatibilities among the different approaches to knowledge and boundaries in organizations. Describing the properties of a boundary in terms of difference and dependence, and the conditions present at a boundary from known to increasing novelty, provides a way to categorize and gauge the complexity of a boundary. The framework also outlines the characteristics of the boundary processes required for each type of boundary. Finally, the framework provides an integrative way to assess the value and costs associated with each approach to managing knowledge across a boundary. The case helped demonstrate the usefulness of the framework by describing a “typical” failure as a mismatch between the type of boundary and the type of boundary approach or process used to manage the boundary.

The fact that most innovation occurs at the boundaries (Leonard-Barton, 1995) reminds us that managing knowledge across the various types of boundaries in an organization is what lies at the source of competitive advantage. Applied to strategic questions, the framework provides a concrete way to describe core strategic concepts such as dynamic capability (Teece, Pisano and Shuen, 1997) where the stated concern has been how to change old knowledge in order to create new knowledge in a firm. The case described and the characteristics of a boundary process identified provide an example of what is required (or lacking) in developing a dynamic or pragmatic capability at a pragmatic boundary. At a firm level, a dynamic capability can be thought of as a portfolio of different types of boundary processes or infrastructures used to manage the knowledge at various boundaries that make up the firm. So, instead of seeing the firm as a bundle of resources (Barney, 1991) a more useful description when it comes to the challenge of establishing and maintaining a dynamic capability is to see the firm as a bundle of different types of boundaries to be managed. The “3-T” framework provides a concrete description of such boundaries and potentially a fruitful ground to link organizational and strategic views of a firm.

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Table 1
Comparative Summary of Approaches to Boundaries

	Syntactic Approach	**Semantic Approach**	**Pragmatic Approach**
Assumptions	Syntax/language is shared and sufficient. Differences and dependencies are clear (stable) at the boundary.	Interpretations and meanings are different. Differences and dependencies are not clear at the boundary.	The knowledge accumulated by one group is not neutral or indifferent to another's. Negative consequences have to be resolved at the boundary.
Solutions	Information Processing (Lawrence and Lorsch, 1967) and knowledge transfer. Taxonomies and repositories (i.e., information technologies) (Davenport and Prusak, 1998).	Translating and learning processes (i.e., communities of practice). Create "shared meanings" and agreements (Nonaka and Takeuchi, 1995).	Current and more novel knowledge must be "jointly" transformed to manage the boundary. Boundary objects and boundary processes (Star, 1989; Carlile, 2002)
Challenges	Capacity to process information (Galbraith, 1973) or transfer knowledge. **Shared syntax is necessary, but not always sufficient!**	Knowledge is hard to surface—it is tacit (Polanyi, 1966). **Differences at a boundary often generate negative consequences!**	Transforming knowledge that is "at stake" (Bourdieu and Wacquant, 1992). **Representing, negotiating and transforming knowledge at the boundary!**

Figure 1
Gauging the Gap: Framing the Complexity of a Boundary

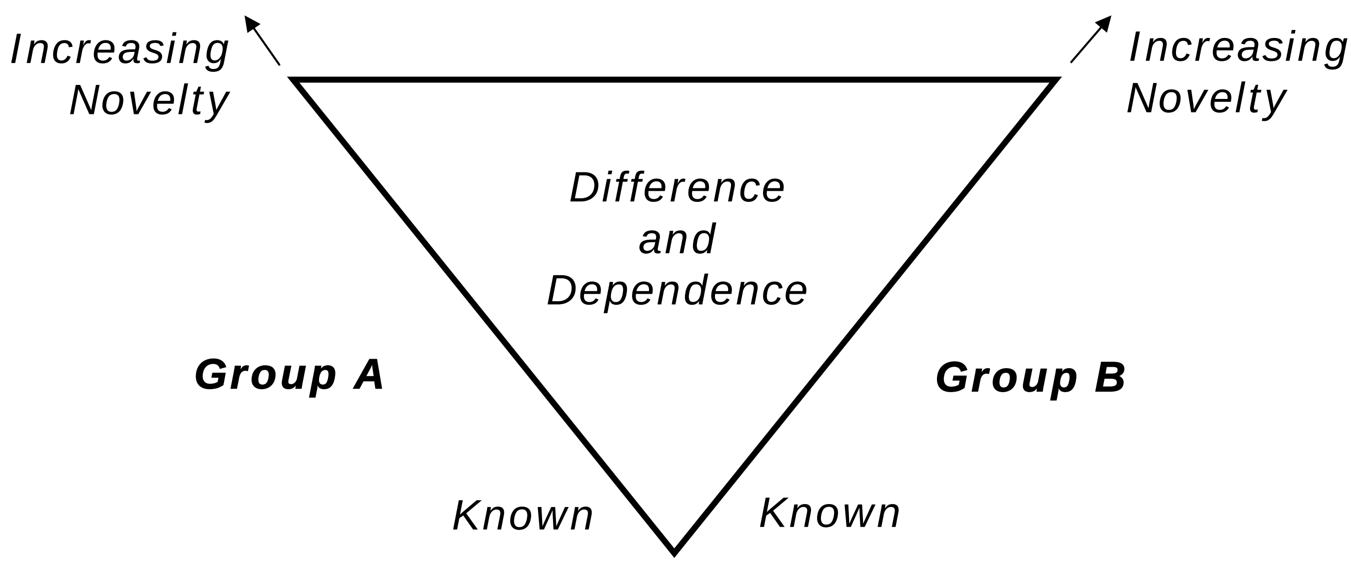


Figure 2
An Integrated/3-T Framework for Managing Knowledge across Boundaries

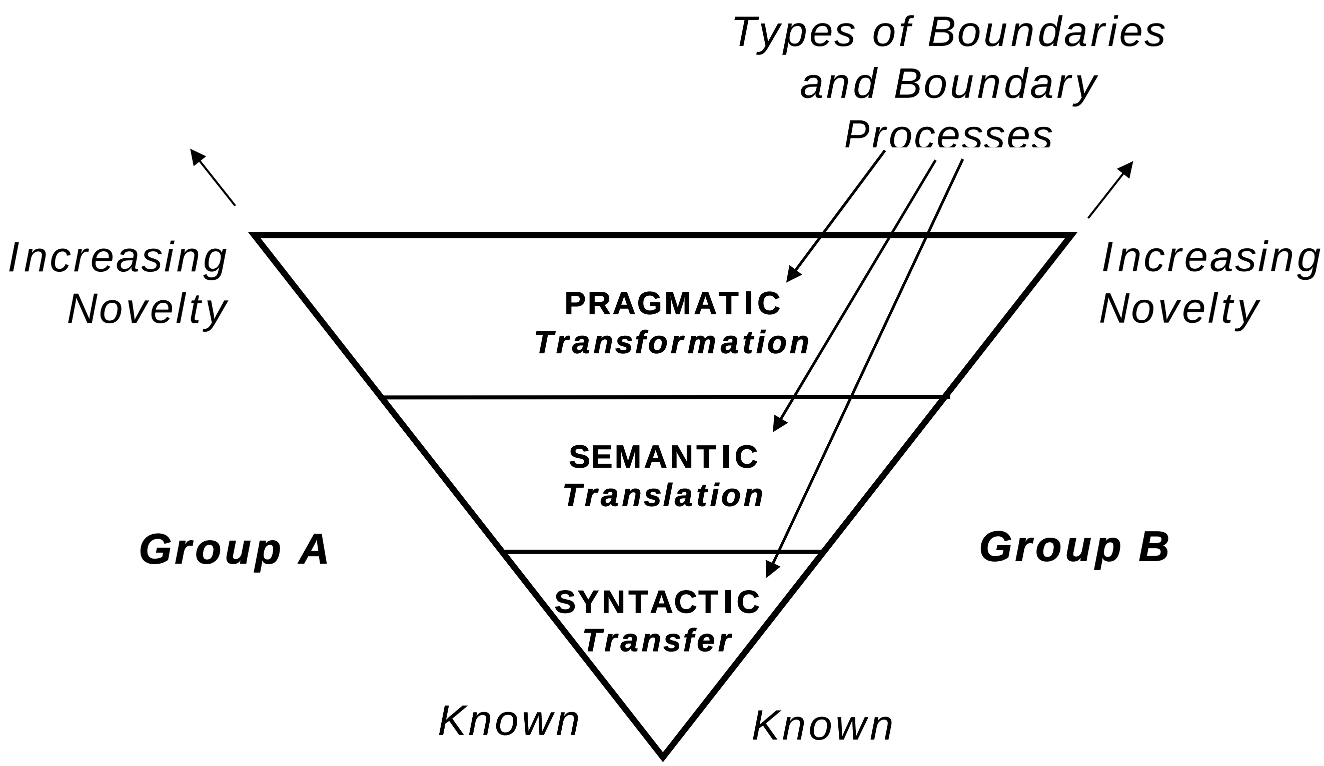
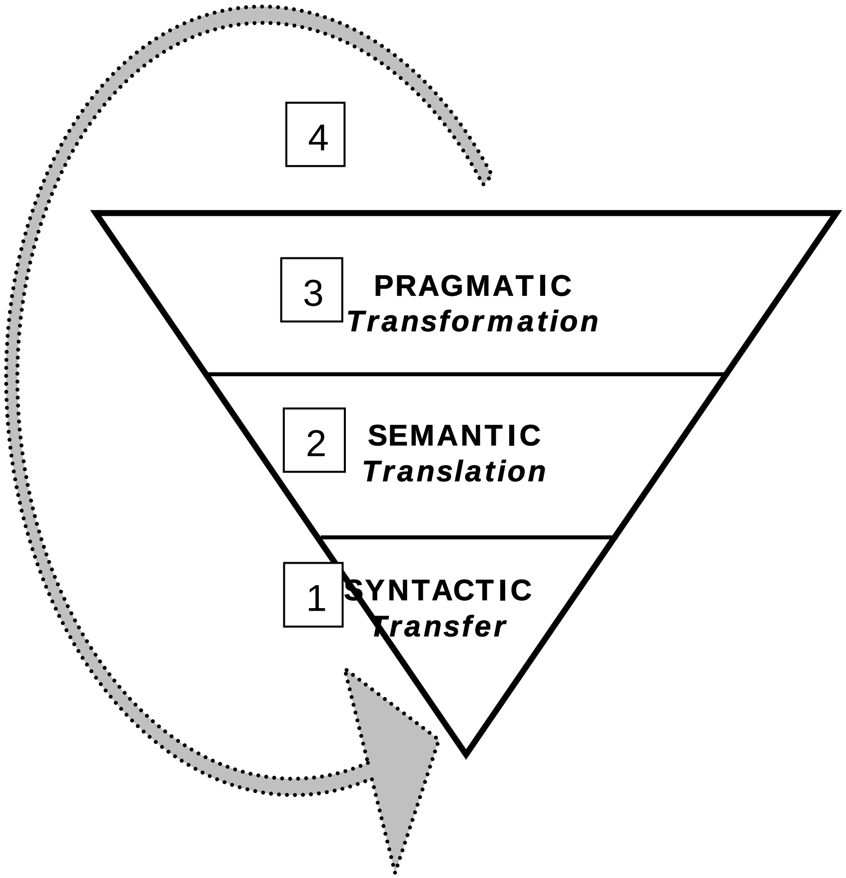


Figure 3

3-T Framework and the Four Characteristics of a "Pragmatic" Boundary Process



4 Supports an **iterative approach** where individuals get better at representing, specifying and transforming knowledge.

3 Allows individuals to negotiate, validate and **transform their knowledge** in order to create new knowledge.

2 Provides individuals a **concrete means of specifying** their differences and dependencies.

1 Establishes some **shared language / syntax for representing** each other's knowledge.